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LASER HEATING OF IONIZED HELIUM

by Victor E. Scherrer

Electronics Research Center
Cambridge, Mass. 02139

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LASER HEATING OF IONIZED HELIUM

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SUMMARY

A method of generating a plasma by combined electrical and laser heating has been developed. An arc, formed between two needle electrodes heated the helium gas to an electron temperature of 10 to 20 eV. At this temperature, the helium was partially ionized. The pre-ionized helium was further heated by a focused laser beam. With a laser power of 15 to 25 MW giving a power density of 3 to 5 x 10^{10} W/cm^2 at the focus, the helium temperature was increased to 26 to 42 eV. Time resolved spectral techniques (ref. 1) were used to measure the temperature of the gas.

INTRODUCTION

A method of generating high energy density plasmas by electrically heating He gas, which was then further heated by a focused laser beam, has been developed. The electrical preheating established a high density of free electrons in the plasma, which absorbed laser light. This electrical preheating arrangement has the advantage over laser heating of cold gas targets, of efficient laser heating. Therefore, only a small, low powered laser is required.

The objective of this study was to develop a high temperature He test gas for spectral and other plasma diagnostic measurements.

DESCRIPTION OF THE EXPERIMENT

In this experiment, two energy sources, a capacitor storing electrical energy, and a Q-switched ruby laser were used to heat helium gas to high temperatures for plasma diagnostic studies. The electrical discharge first heated the gas between two needle-shaped electrodes. When 2.5 J of electrical energy were deposited in helium, it was heated to a kinetic electron temperature of about 10 eV. When the arc current reached a maximum, a ruby laser beam, focused on the arc, further heated the helium gas, resulting in temperatures of 26 to 42 eV.

A schematic diagram of the experiment is shown in Figure 1. The electrical arc used tungsten electrodes with the tips separated 500 µ. The average tip radius was 25 µ. The arc tube was filled with He gas; the ambient gas pressure was 700 torr.

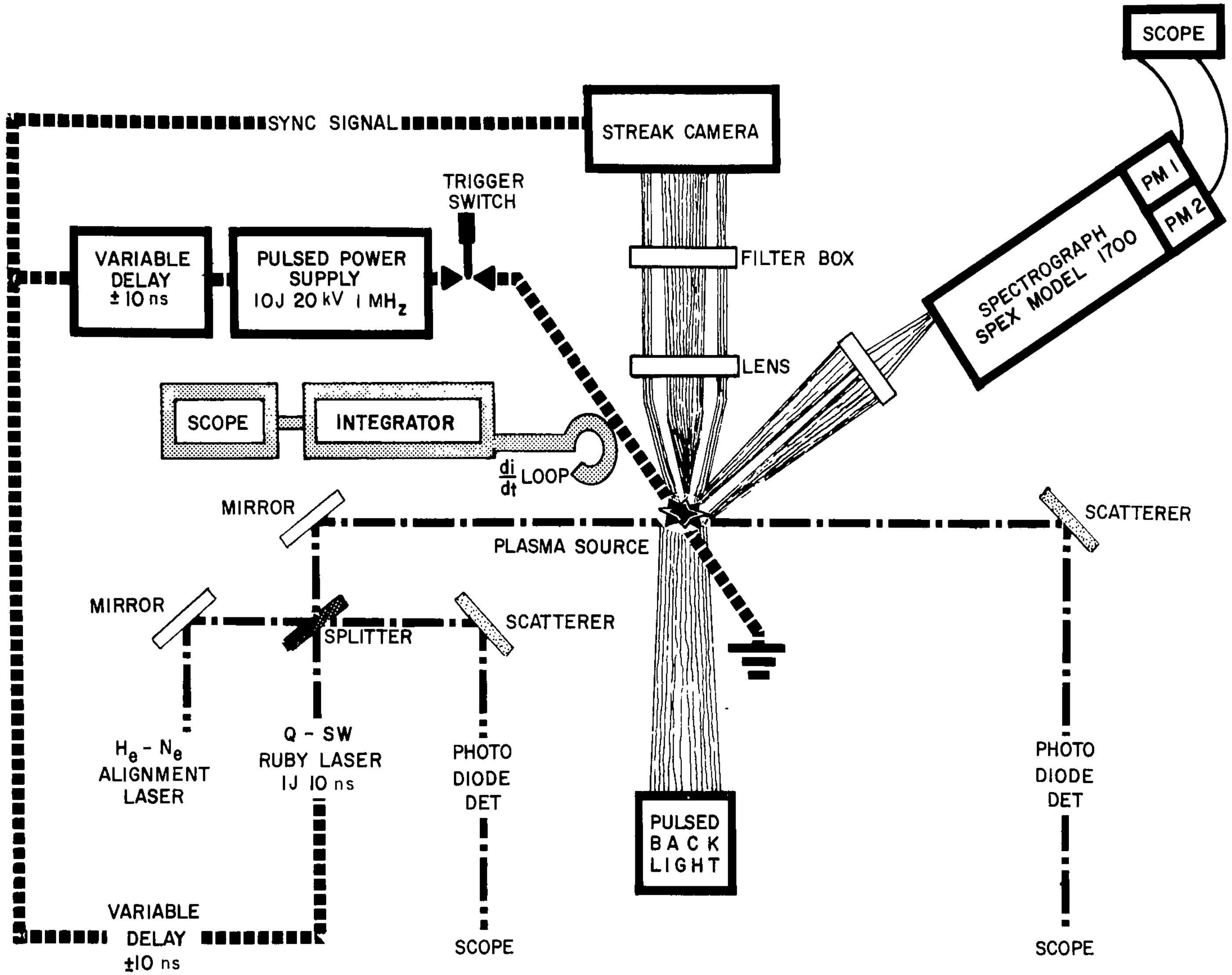

Figure 1.- Schematic diagram of laser heating experiment

An arc was generated when the capacitor (.05 μF) was connected across the electrodes by a triggered air gap switch. The capacitor stored 10 J of energy at a potential of 20 kV. The discharge frequency was 1 MHz. The initial arc diameter, midway between electrodes was 1 mm, and expanded to a diameter of 3 mm at peak current.

The arc was heated by a ruby laser (6943 Å) having a 15-ns pulse; the peak power was 25 MW. Trigger circuits fired the laser at any preset time relative to the electrical discharge. The maximum time jitter was ± 10 ns.

In the electrical heating circuit, current through and voltage across the arc were monitored. The incident and transmitted laser light was monitored with 1.5-ns resolution. A Beckmann and Whitley Model 200 streak-framing camera was used to observe radial motion of ionized helium in the arc. Time resolution of the streak camera was 20 ns.

A SPEX Model 1700 spectrograph was used to observe the spectral distribution of emitted radiation. The electron temperature of the plasma was deduced from these measurements.

EXPERIMENTAL RESULTS

Figure 2 is a streak picture which shows the expansion of electrically heated helium midway between electrodes. It expanded to a diameter of 3 mm in 100 ns.

When the current through the arc reached its maximum, the Q-switch was triggered, resulting in a laser light pulse incident upon the ionized helium. Since the helium was ionized, much of the light was absorbed, thus further heating the helium plasma.

The mechanisms by which laser light was absorbed have not been positively established, but a likely mechanism is the "inverse bremsstrahlung effect" (ref. 2). For this energy absorbtion mechanism, the quantity of light absorbed depends upon the density of free electrons in the target.

Figure 3 shows the results of measuring the laser light absorbed in the transient arc source. The percent of incident laser light is plotted against the ambient helium gas pressure. As indicated in the figure, the target becomes more transparent for helium pressures below 300 torr. The percent of laser light absorbed is almost constant for ambient gas pressures above 400 torr.

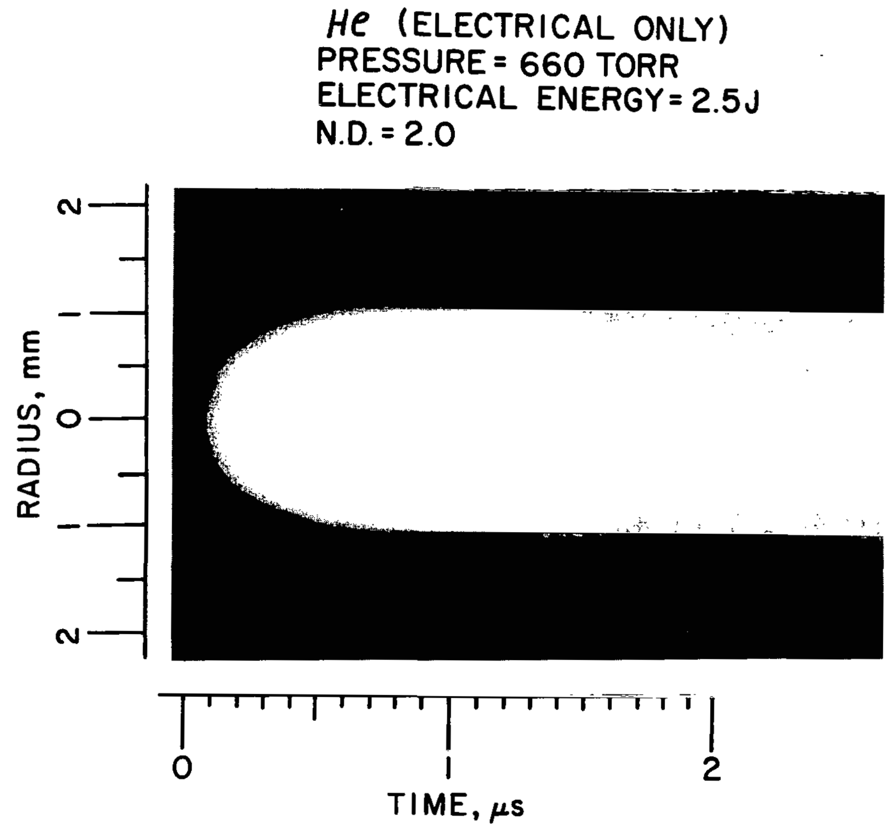

Figure 2.- Streak picture showing plasma expansion due to electrical heating

Figures 4 and 5 show streak pictures taken during laser heating. The ambient helium pressure for the picture shown in Figure 4 was 160 torr. The direction of the incident laser light is indicated in the figure. The laser light was absorbed throughout the expanding plasma. The streak picture shown in Figure 5 shows laser heating of an arc occurring in helium having an ambient pressure of 400 torr. In this case, most of the laser heating occurred on the side of the helium plasma corresponding to the incident laser light.

The kinetic electron temperature of the plasma in the transient arc was measured with and without laser heating. The results are shown in Table I. The stored energy for the electrical discharge was 2.5 J. The average laser heating power for each of four shots is given in the first column. The estimated power density in the focused laser beam is given in the second column. The electron temperature, T_1, of the arc at the instant of time when the laser was fired is shown in the third column.

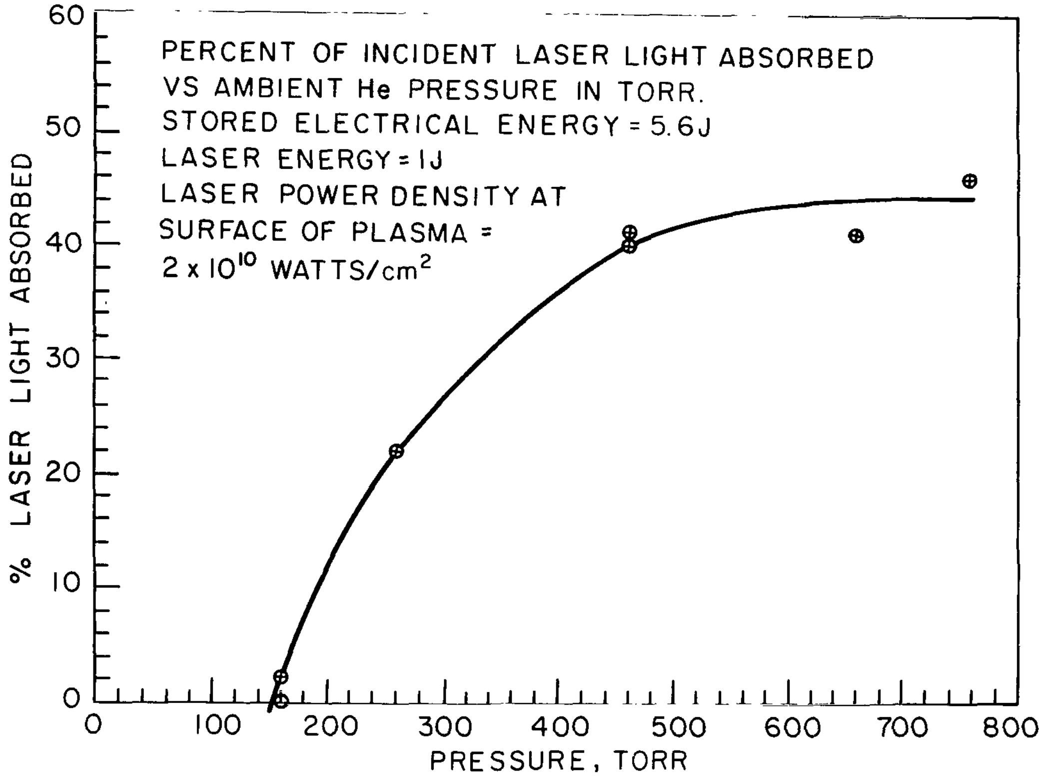

Figure 3.- Absorbtion of laser light in the helium arc

TABLE I.- LASER HEATING OF PRE-IONIZED TARGET

Average Input Laser Power MW	Focused Laser Power MW/cm^2	T_1 eV	T_2 eV
12	10^{10}	10	27
20	1.67×10^{10}	11	24
22	1.83×10^{10}	11	40
24	2×10^{10}	10	55

The temperature due to electrical heating alone varied from 10 to 15 eV. This temperature was determined by the intensity ratio of the HeI 4686-Å line to background continuum technique (ref. 1). The fourth column gives the peak electron temperature, T_2, attained due to laser heating. The temperature measurements were made using the intensity ratio of the spectral lines (ref. 1) HeI (4922 Å) to HeI (4713 Å).

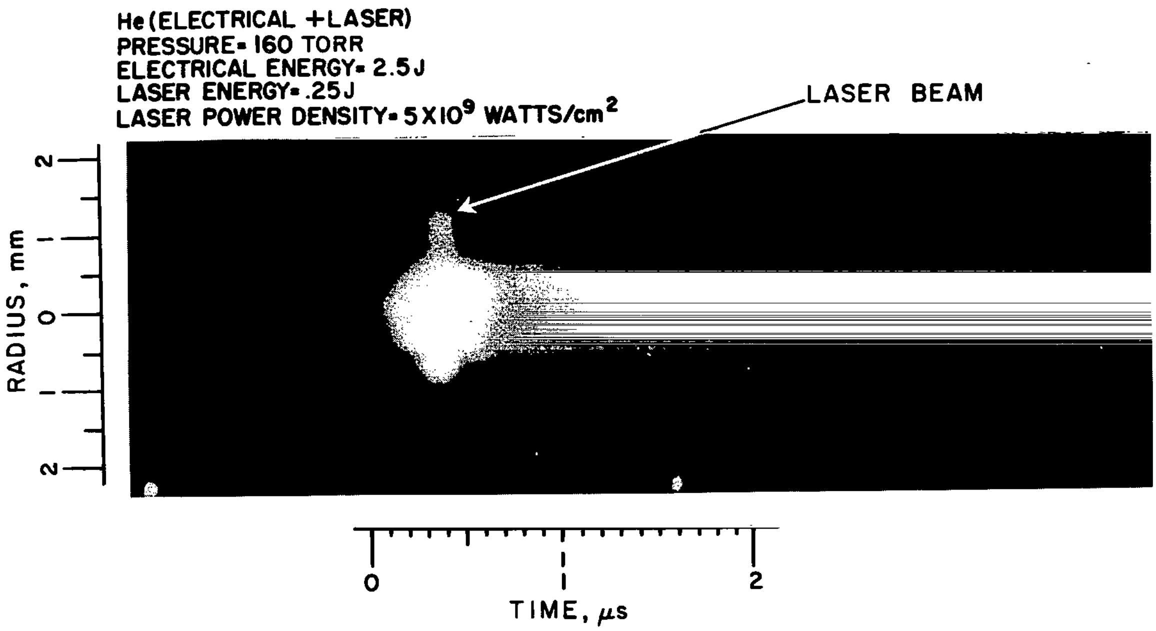

Figure 4.- Streak picture showing laser heating of He at low pressure

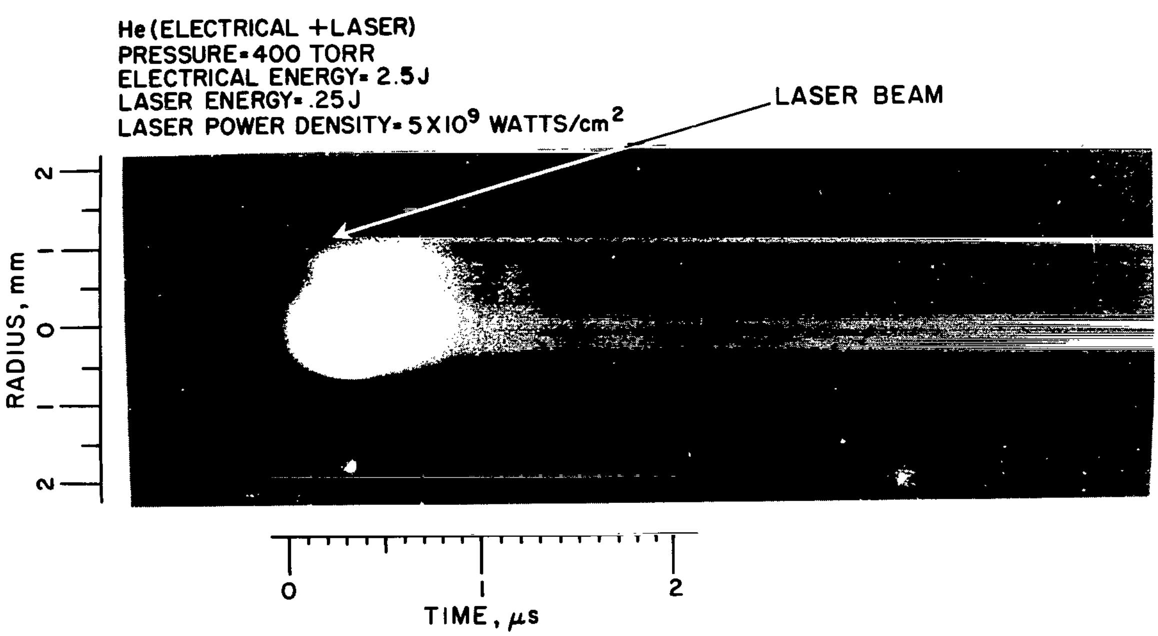

Figure 5.- Streak picture showing effects of laser heating of He (400 torr)

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